Possible solution to consumption-rate equation problem:

Use species-specific FB4 meta models

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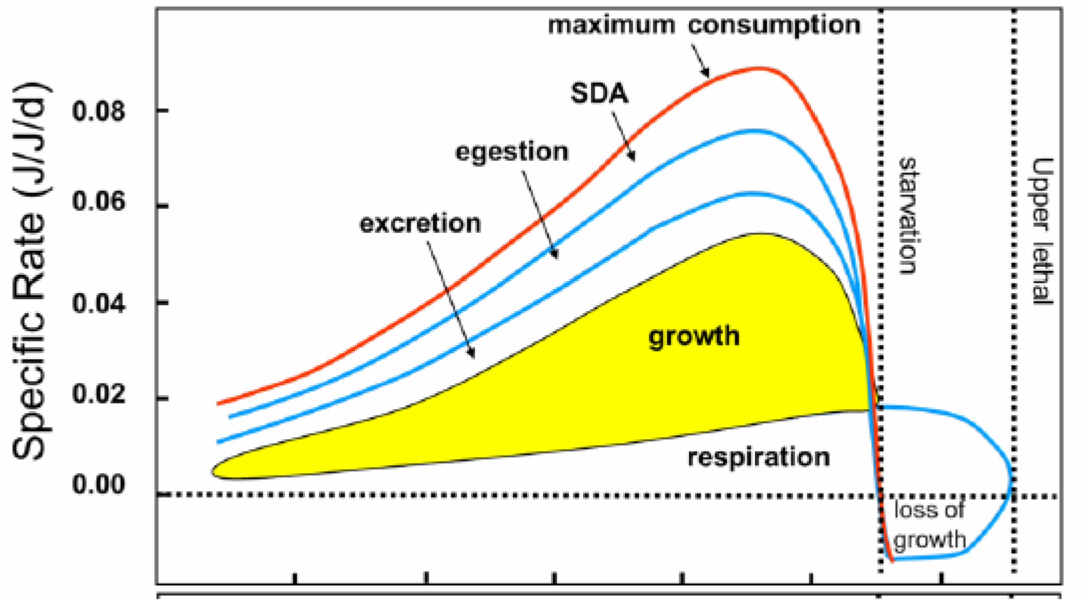
Fish Bioenergetics 4.0

- http://fishbioenergetics.org/
- https://github.com/jim-breck/FB4/blob/master/FB4_User_Guide.pdf
- 105 published bioenergetics models

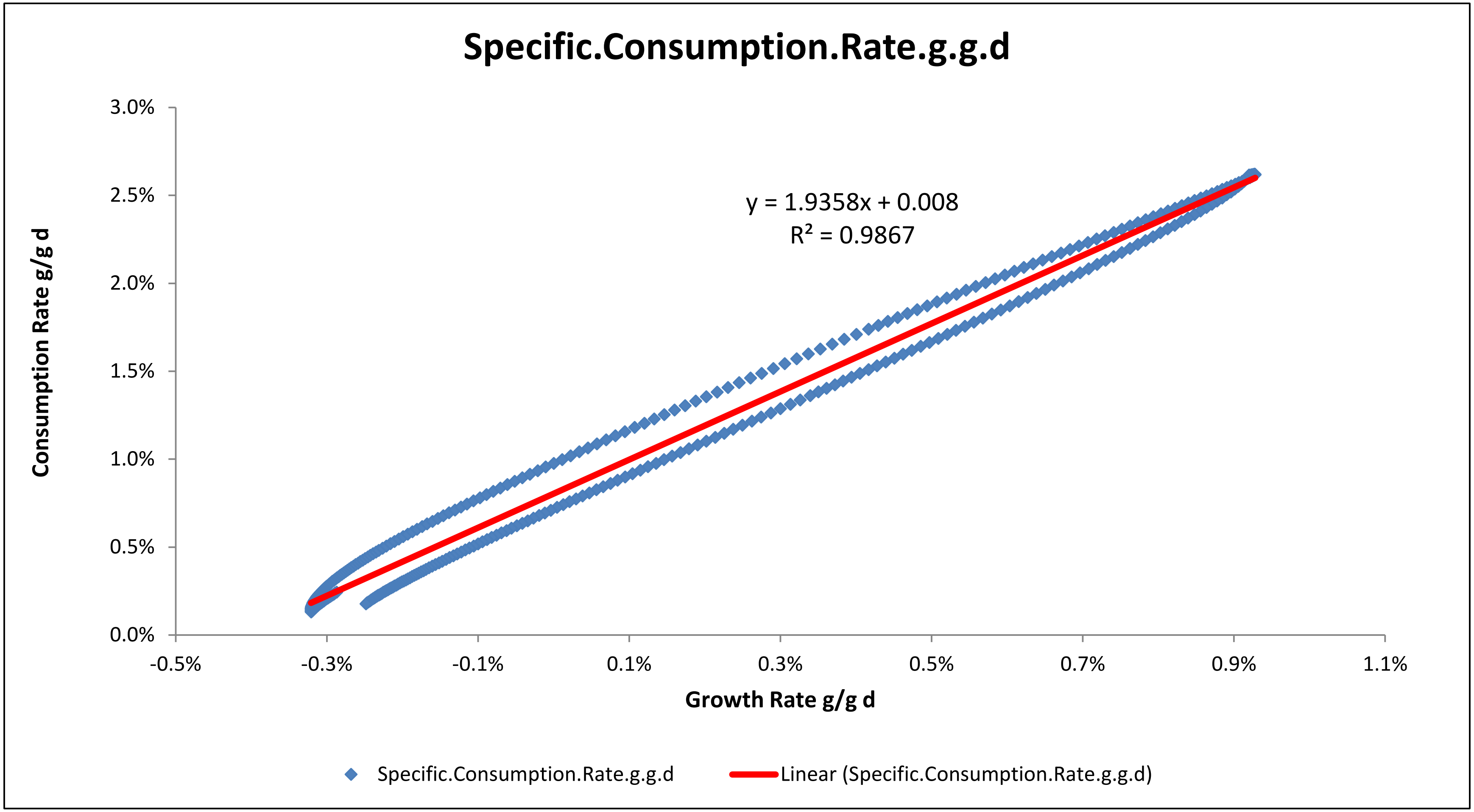


Example Largemouth Bass Model

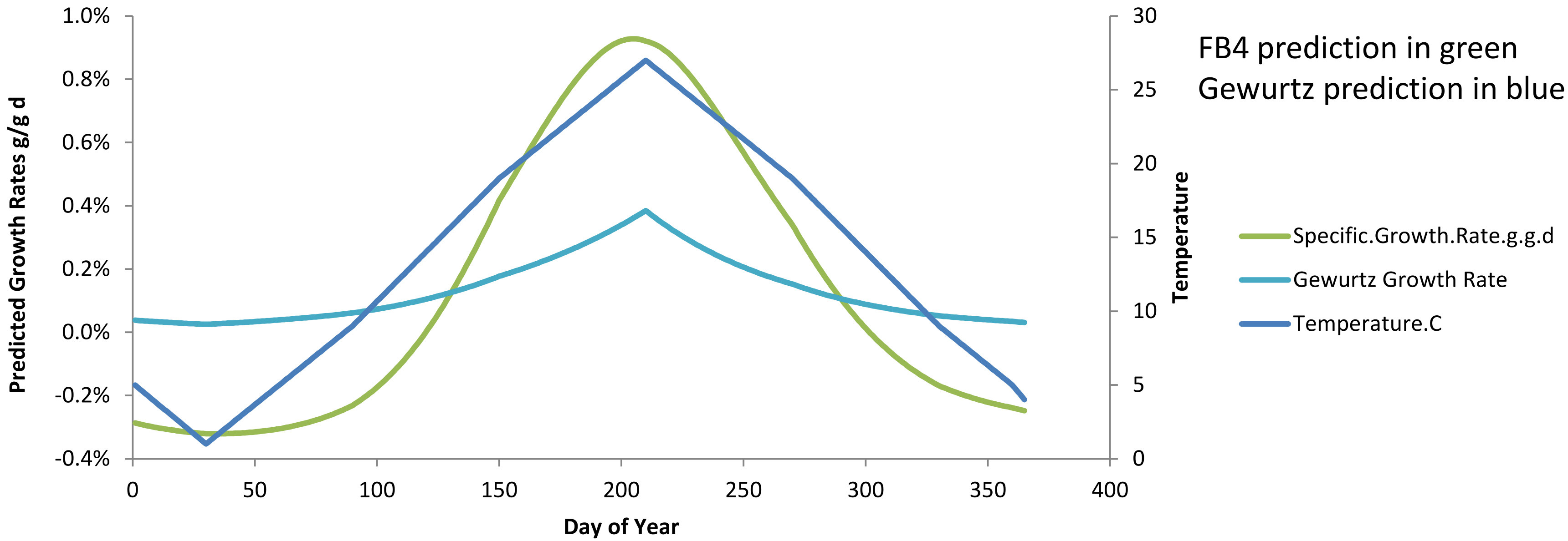
- Parameters
  - Initial Weight = 290 g
  - Day 365 Weight = 490 g
    - (derived using Gewurtz Growth Equation)
  - Predator energy density 4500 J/g, Prey 4000 J/g
    - Approximate defaults for piscivores, can be modified
  - Input Temperature Range 1 to 27 deg. C
    - Consistent with and contains full range of LPR temperatures

Derived LMB Model of consumption as a function of growth rate

Consumption in g/g d = 1.936 multiplied by Growth Rate in g/g d (+0.008 g/g d)



FB4 predicts different impact of temperature on growth rates; may not be important



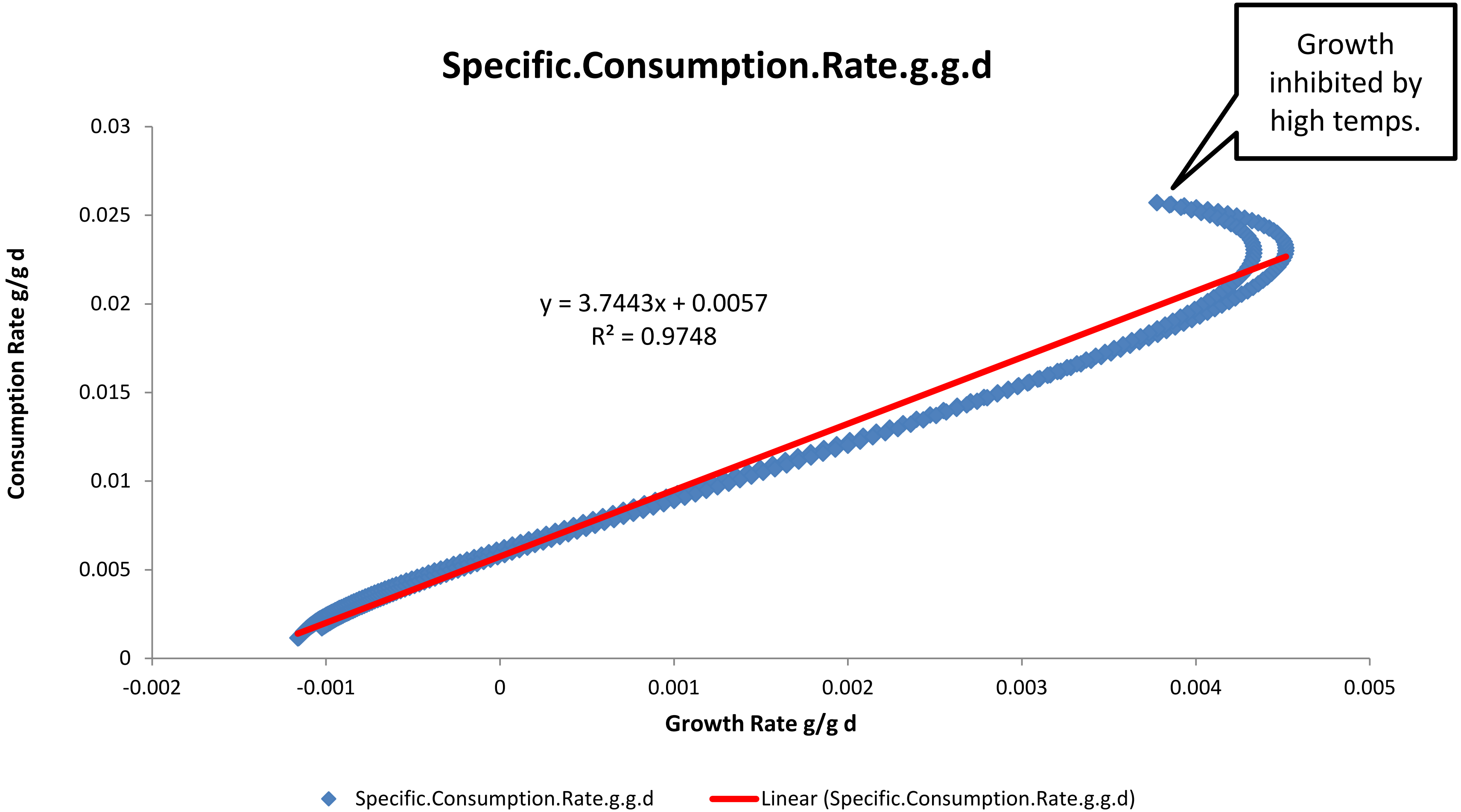
- FB4 growth rate becomes negative during dormant periods and is higher during warmer periods to achieve same overall growth
- Arnot and Gobas model does not calculate weight change over year so this **may** not be important
- The pressing current model need is a relationship between growth rates and food consumption rates

Example Carp Model

- Silver carp– surrogate species
- Initial Weight = 3100
- Day 365 Weight = 4150
  - (derived using Gewurtz Growth Equation)
- Predator energy density 4500 J/g, Prey 3000 J/g
  - Approximate defaults for omnivores, can be modified
- Temperature Range 1-27 deg. C
  - Consistent with and contains range of LPR temperatures

Derived Carp Model of consumption as a function of growth rate

Consumption = 3.74 multiplied by Growth Rate (+0.0057)



Pros and Cons

- Pros
  - Species specific models in several cases
  - Quick to implement
  - Simple linear equation that provides a reasonable estimated consumption rate given an assumed growth rate
  - Literature growth-to-consumption ratios can increase confidence in surrogate-species models
- Cons
  - Would warrant some research on energy densities
    - "a sensitive input parameter in most modeling scenarios (Bartell *et al.* 1986)." FB4 User Guide
    - Can be estimated on the basis of lipid & protein content

$$\lambda = 39.5\, f_L + 20.08\, f_P$$

λ = Energy density of the animal (kJ/g-wet).

f_L = Fraction lipid.

f_P = Fraction protein.

(Brett and Groves, 1979)

  - Need to use surrogate-species model in many cases

FB4 Models

- Alewife (adult)
- Alewife (yearling)
- Alewife (YOY)
- Alewife (larval)
- Atlantic cod (juvenile & adult)
- Atlantic menhaden (YOY)
- Baikal Grayling
- Baltic herring (YOY)
- Bay anchovy (juvenile & adult)
- **Bighead carp**
- Bloater chub (adult)
- **Blue Crab (external publication)**
  (Brylawski and Miller 2003)
- Bluefish (age 0-2)
- Bluegill sunfish (adult)
- Bluegill sunfish (juvenile)
- Brook Trout (juvenile & adult)
- Brown Bullhead
- Brown Trout
- Bull trout (adult)
- Burbot (juvenile & adult)
- **California Killifish (juvenile & adult)**
- Chinook salmon (adult)
- Coho salmon (adult)
- Cutthroat trout
- Dace (adult & juvenile)
- Eurasian perch (1 g)
- **Eurasian perch (100 g)**
- Eurasian perch (larvae & YOY)
- European anchovy (adult)
- European anchovy (egg & larvae)
- European anchovy (juvenile)
- European smelt (larvae & juvenile)
- European whitefish (larvae & juvenile)
- Fathead minnow
- **Generalised coregonid**
- Gizzard shad
- Herring (adult)
- Herring (juvenile)
- Humpback chub (juvenile & sub-adult)
- Indo-Pacific Lionfish (juvenile & adult)
- Lake trout (adult)
- Lake whitefish (adult)
- **Largemouth bass (adult)**
- Lenok
- Lingcod
- Muskellunge (adult)
- **Mysis (adult) (invertebrate)**
- Nile perch
- North Sea cod
- Northern pike (adult)
- Northern pikeminnow
- Pacific Saury (adult)
- Pacific Saury (juvenile)
- Pallid sturgeon (juvenile)
- Pallid sturgeon (larvae)
- Pink salmon (adult)
- **Plains killifish (mummichog?)**
- Prickly Sculpin (adult)
- Rainbow smelt (adult)
- Rainbow smelt (juvenile)
- Rainbow smelt (YOY)
- Rainbow Trout (juvenile)
- Rainbow Trout (adult)
- Red River shiner
- Roach
- Round goby
- Ruffe
- **Rusty crayfish (crab or invert?)**
- Sacramento perch
- Saugeye
- Sea lamprey
- **Silver carp**
- Smallmouth Bass (T>26 & sub-adult & adult)
- Smallmouth Bass (T<=26 & sub-adult & adult)
- **Smallmouth bass (adult)**
- Snakehead (juvenile)
- Sockeye salmon (adult)
- Southern flounder
- Steelhead (adult)
- Striped bass (adult)
- Striped bass (age-0)
- Striped bass (age-1)
- Striped bass (age-2)
- Striped bass (larvae)
- Tiger Muskellunge (adult)
- Tiger Muskellunge (juvenile)
- Tilapia (adult)
- Threespine Stickleback
- Vendace (larvae & juvenile)
- Walleye (adult)
- Walleye (larvae & juvenile)
- Walleye pollock (>400 g)
- Walleye pollock (100-299 g)
- Walleye pollock (300-400 g)
- Walleye pollock (adult)
- Walleye pollock (juvenile)
- Weakfish (age-0)
- Weakfish (juvenile & adult)
- Western mosquitofish (juvenile & adult)
- White bass (larvae)
- White crappie (adult)
- **Yellow perch (adult)**
- Yellow perch (juvenile)
- Yellow perch (larvae)
- Zander (adult)
- Zebra mussel (adult)

Each model has an associated reference that should probably be reviewed (to understand temperature ranges of observed data, for example)

Important Note

- Growth rates would now be the driver of model bioenergetics / food-consumption rates
- Gewurtz growth equation must be verified as reasonable given species and site-specific data
- For example,
  - Mean carp weight ~3100
  - If start year at mean weight, Gewurtz predicts end-of-year weight at 4180
  - However this exceeds highest measured carp weight ~3900
  - Suggests predicted growth rates are a bit too high for this species
  - Additional verification is warranted

Growth Rate Model

- Gewurtz curve, reference: Thomann 1992 which references Thomann 1982.
- Thomann: "A **very approximate** estimate of the growth as a function of organism size, can be derived the data compiled by Sheldon et al. 1972)" (emphasis added)
- Sheldon et al, 1972: "The Size Distribution Of Particles in the Ocean" *Limnology and Oceanology*
- Meta-analysis of oceanic growth-rate data

Sheldon 1972

The Size Distribution Of Particles in the Ocean

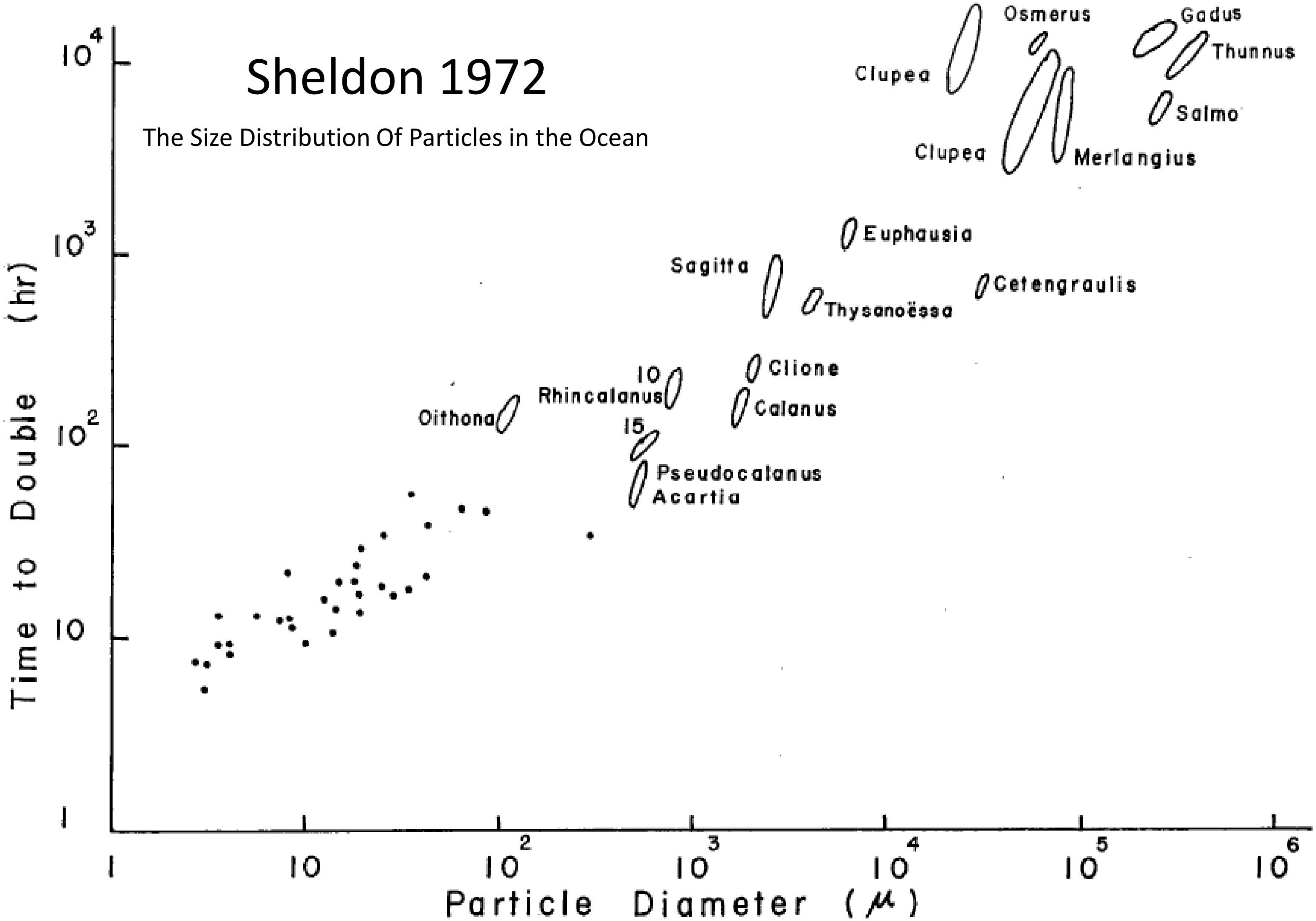
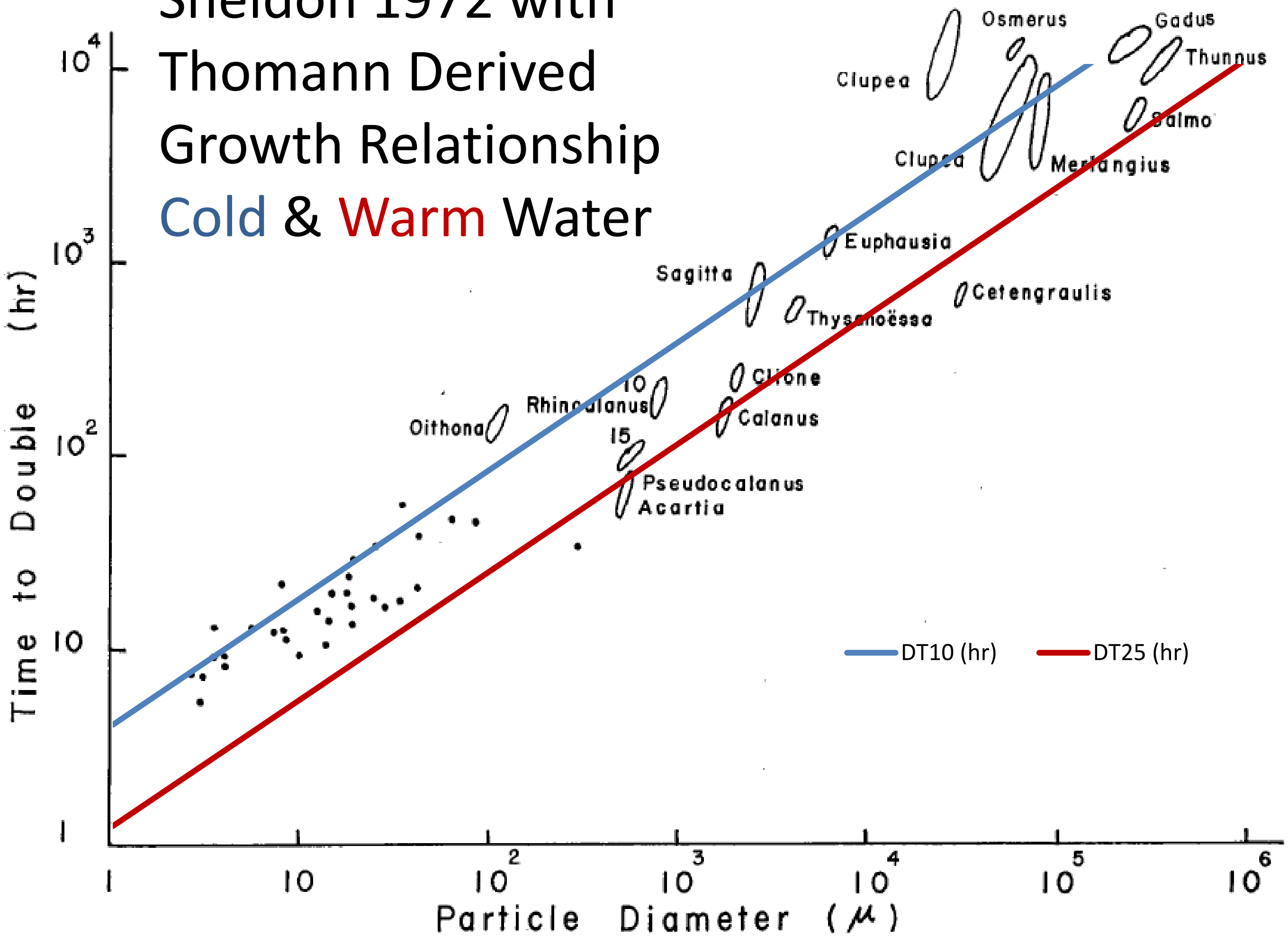


FIG. 13. The relationship between rate of production and particle size. The numbers near to the *Rhincalanus* patches indicate the temperature at which the growth took place. The uppermost of the two *Clupea* areas represents *C. sprattus*. The lower area represents both the Atlantic (*C. harengus*) and Pacific (*C. pallasi*) herring. For other explanations *see text.* Data from Altman and Dittmer (1964), Conover and Lalli (1972), Einarsson (1945), Eppley and Sloan (1966), Ford (1933), Garrod and Gambell (1965), Heinle (1966), Johnson (1970), Lebour (1925), Marshall and Orr (1955), MacLaren (1965, 1969), Mullin and Brooks (1970), Prakash (1967), Smayda (1966), and Williams (1964).

Sheldon re: Temperature

- "Growth rate varies with temperature but this effect is small relative to the scale we use... However, the cool-water species tend to fall on the upper part of Fig. 13, indicating that at any one size, rate of production is highest in warm water."

Sheldon 1972 with Thomann Derived Growth Relationship Cold & Warm Water



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Growth Rate Thoughts

- Equation used derived from older marine data
- Extremely generalized – single cell organisms to whales
- Temperature relationship probably pertains to cold water vs. warm water species rather than intra-annual variation
- Does not take into account age-class of fish
- Probably best suited for whole populations or highly generalized equilibrium model; seems ill suited for kinetic model
- However for LPR: sometimes produces reasonable ballpark estimates based on literature and site-specific data

Invertebrate Growth Rates

- Housatonic Calibration report: Gary Lawrence performed extensive literature meta-analysis on invertebrate growth rates

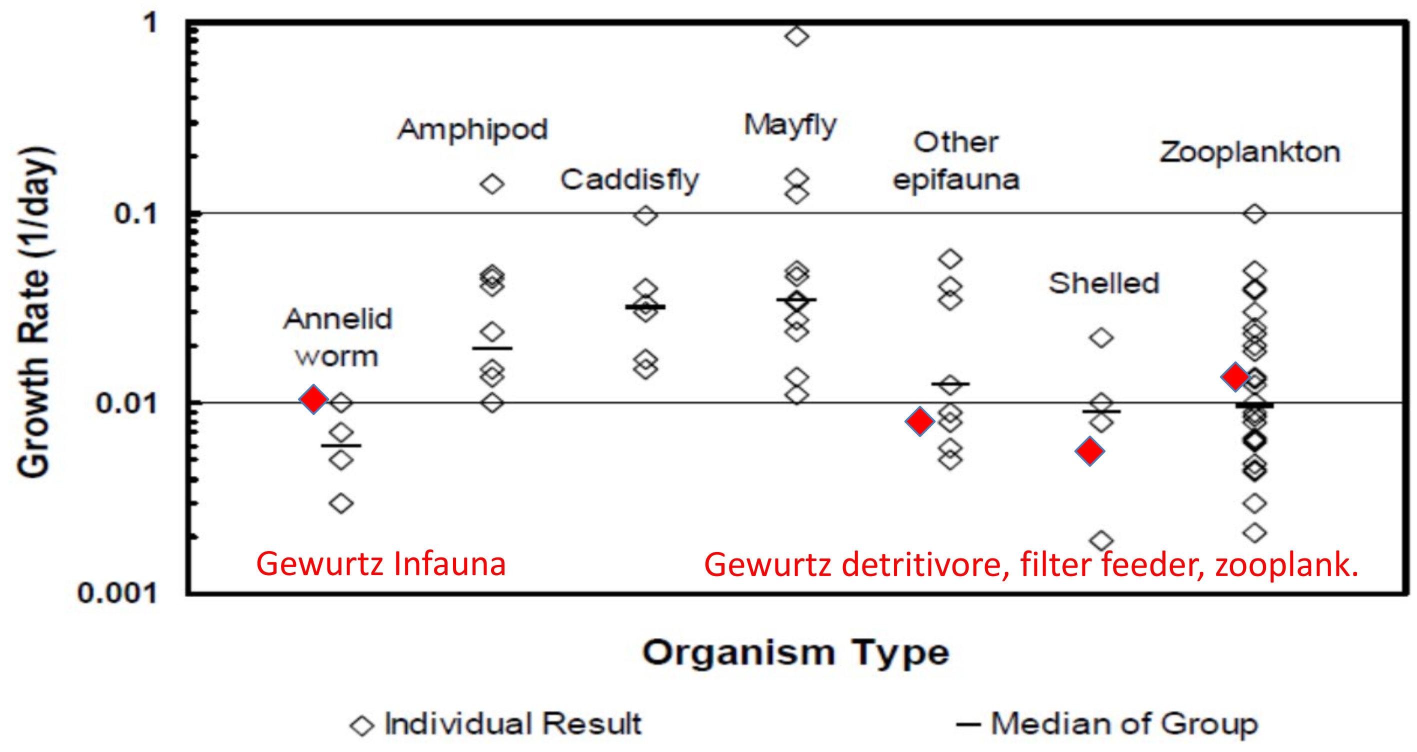

Figure 1 **Growth Rates for Subgroups of Invertebrates (Annelids, Epifauna, and Zooplankton) Considered for FCM Calibration**

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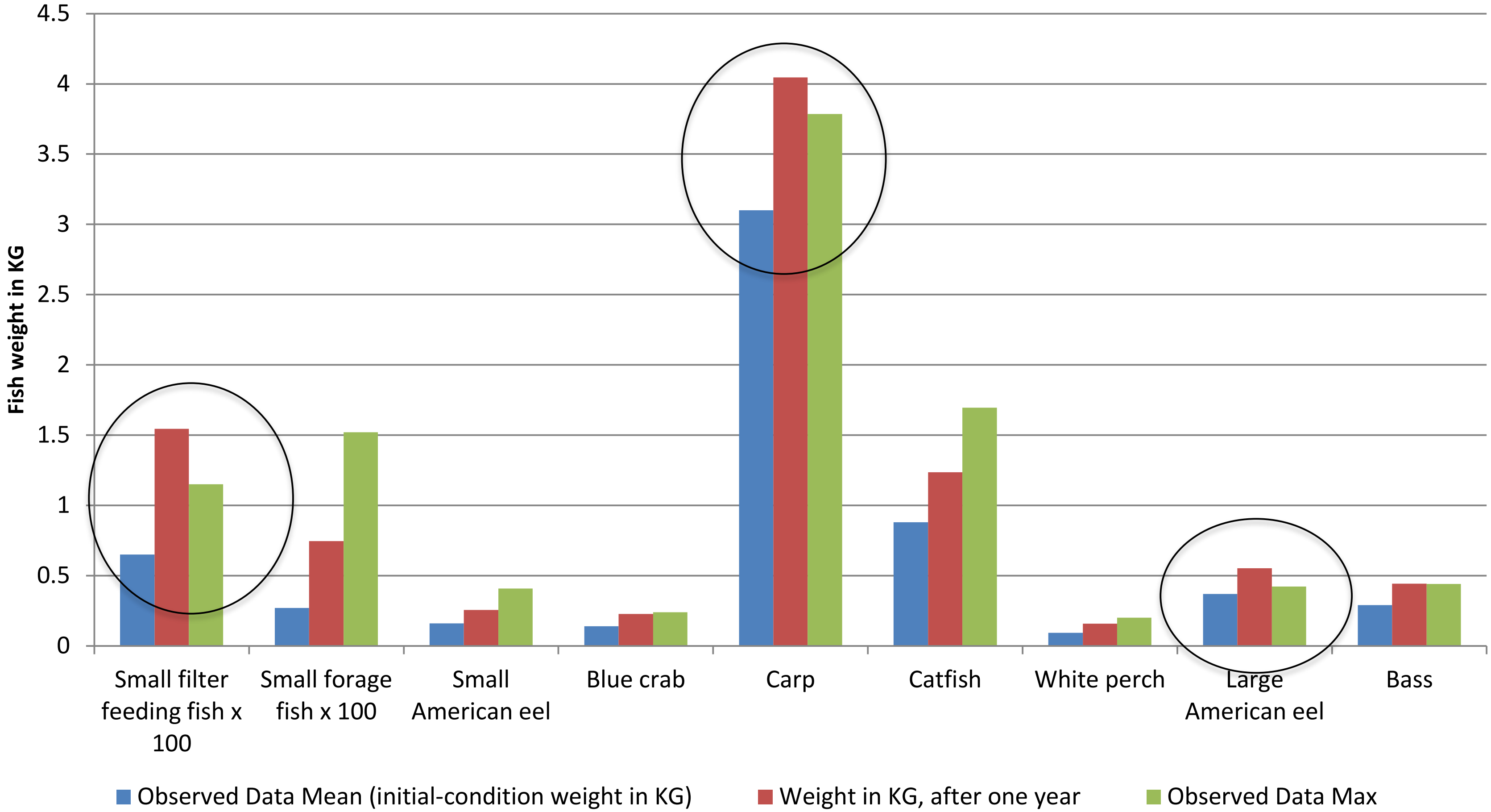
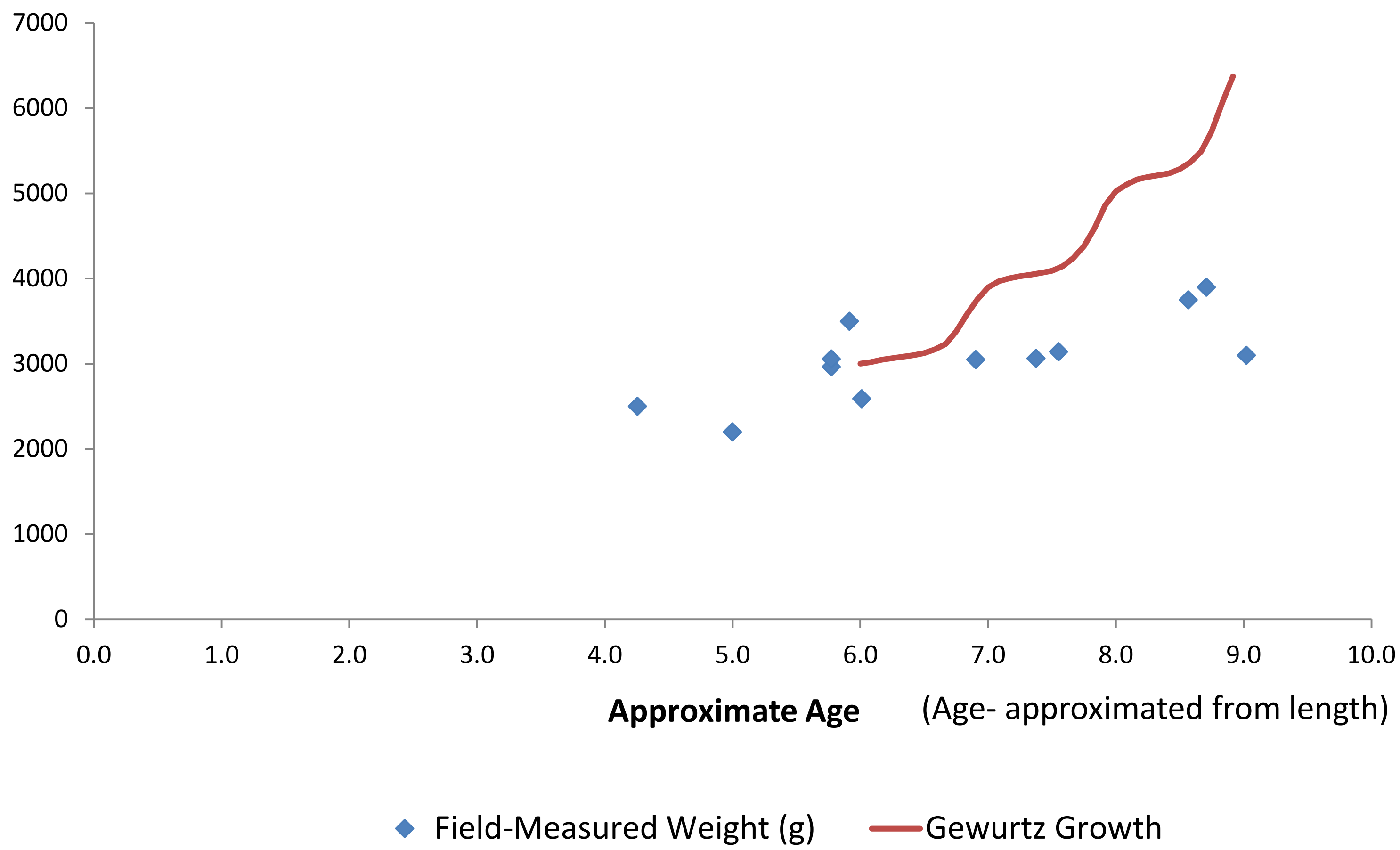
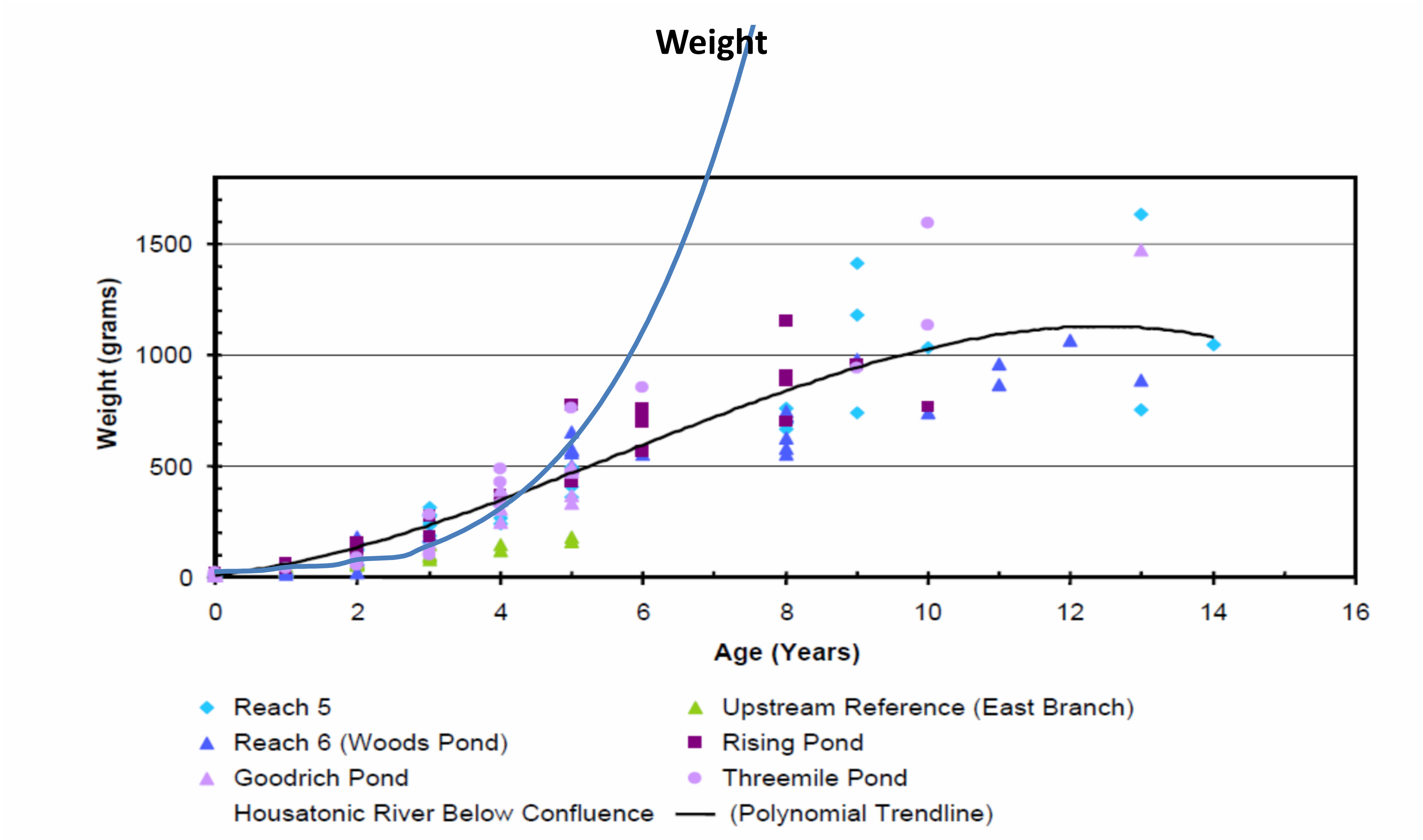
Seeming overpredictions for some fish



Carp Model data vs. prediction



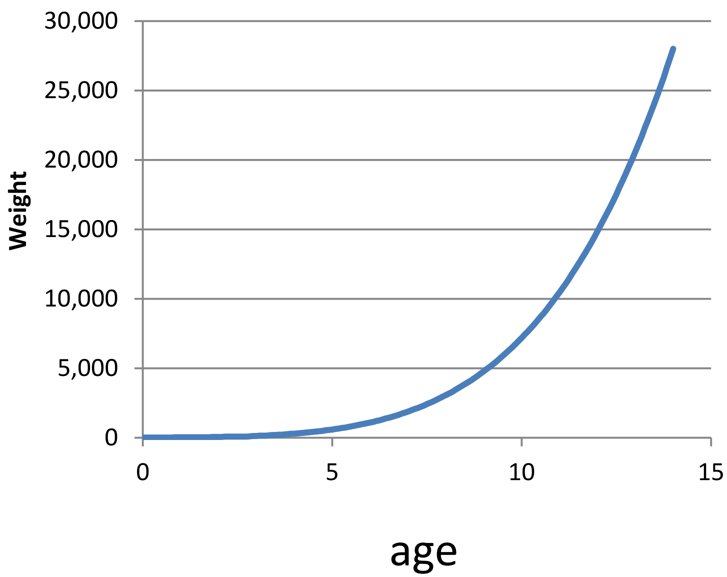
Bass: Gewurtz model vs. Housatonic Data



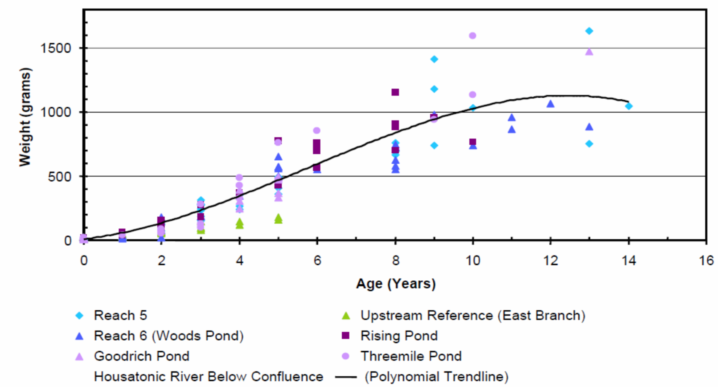
Growth Model Shape

- Exponential shape vs. data/Von Bertalanffy
  - At mature age classes, doubling times becomes infinite as growth slows
  - A model based on population doubling times would not include this detail

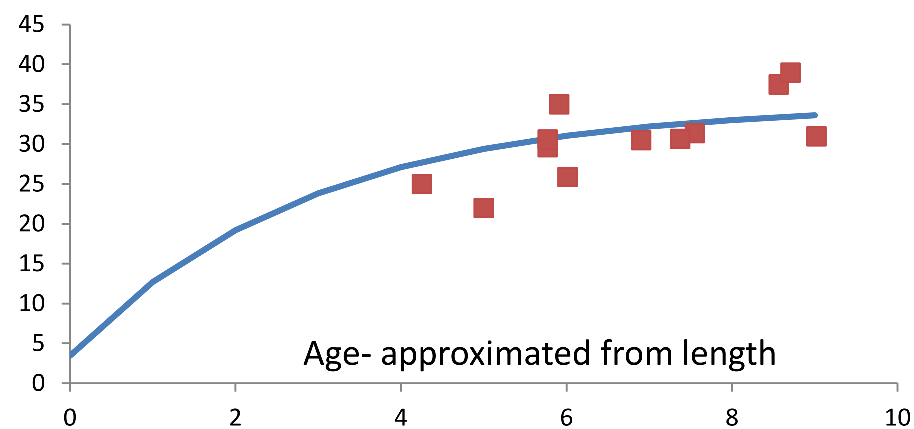
Gewurtz Model
Weight by age class



Housatonic data: weight by age class



Von Bertalanffy Growth Curve fit to LPR Carp Data

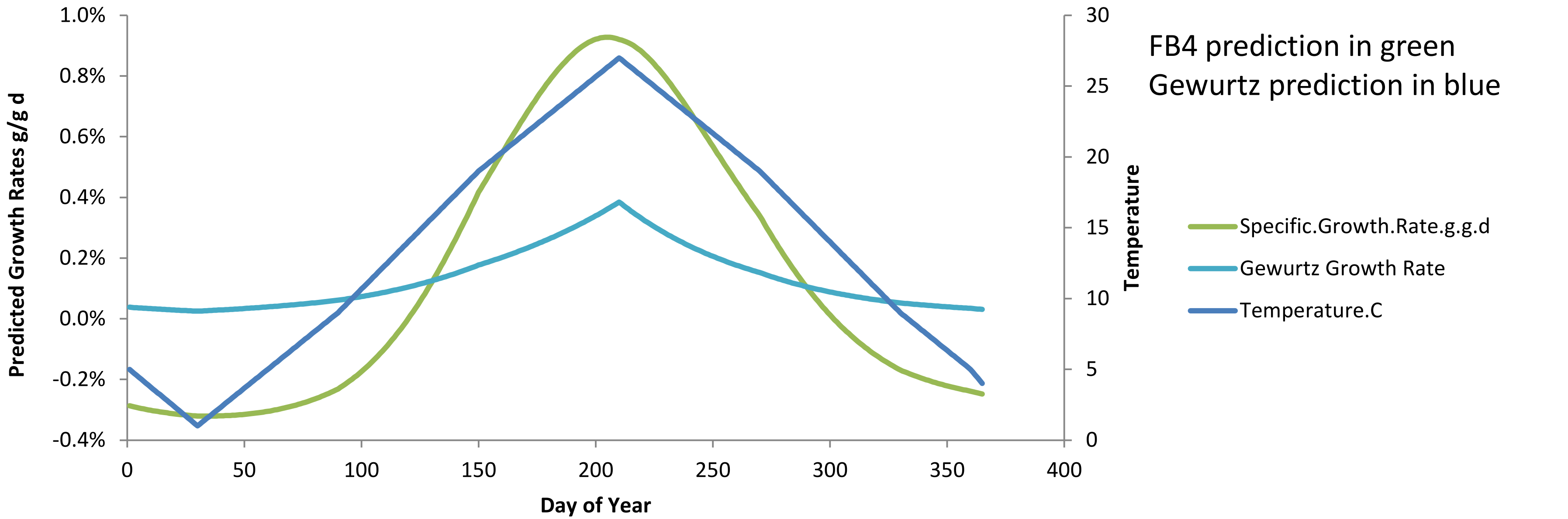


Two Growth Rate Issues

- Determine averaged annual growth rate for size class modeled
  - Gewurtz model (problematic for older size classes)
  - Literature Survey
  - Site-specific data (no age data, but can bound estimate)
  - Fish Bioenergetics 4.0?
    - Potentially problematic – requires accounting of food consumed
    - Fraction of CMAX, Fraction of biomass, etc.

- Distribute growth rate over year
  - Gewurtz model (not strong, based on derivation)
  - Guidance from FB4 (how well would the model handle negative growth rates?)
  - Housatonic approach
    - Dormancy in cold months, fitted exponential growth to observed data during growing season

FB4 predicts different impact of temperature on growth rates; may not be important



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